

ISSUE MEMO

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DATE: January 26, 2005

SUBJECT: Adoption of Mechanistic-Empirical (M-E) Pavement Design Method

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ISSUE:

Under sponsorship of the American Association of State Highway and Transportation Officials (AASHTO) Joint Task Force on Pavements (JTFP), the National Cooperative Highway Research Program (NCHRP) through NCHRP Project 1-37, "Development of the 2002 Guide for the Design of New and Rehabilitated Pavement Structures," and NCHRP Project 1-37A, "Development of the 2002 Guide for the Design of New and Rehabilitated Pavement Structures: Phase II," recently delivered a new pavement design procedure for both rigid and flexible pavements that is fully mechanistic-empirical (M-E) in approach. M-E pavement design is based on evaluating historical performance of pavement materials and designs in various environments and from those evaluations, developing prediction models that will more accurately predict pavement performance.

If adopted, the M-E pavement design methodology would replace existing pavement design methods, which have been in place since the early 1950s. The purpose of this paper is to evaluate the benefits and impacts to the California Department of Transportation (Caltrans) of adopting the M-E pavement design approach and to determine if making this change is in its best interest.

BACKGROUND:

The M-E pavement design approach has been under development since the 1960s. The same basic approach has been used in a variety of pavement design procedures since the 1980s, such as the Shell Method, the Asphalt Institute Method for asphalt pavements, the Illinois Department of Transportation's (DOT's) method for rigid pavements, and in other procedures developed by several state DOTs. The M-E approach is the standard approach used by pavement consultants around the world and is taught in every major university in the United States.

Both the 1986 and 1993 editions of the *AASHTO Guide for Design of Pavement Structures* incorporated some M-E pavement design principles for rigid pavements but kept essentially the same empirical procedure based on the AASHTO Road Test conducted between 1958 and 1960. Beginning in 1996, Caltrans started working in cooperation with other states, through NCHRP Projects 1-37 and 1-37A, to develop a performance-based pavement design method using the M-E approach. The M-E pavement design approach originally was scheduled to be implemented in 2002 as AASHTO's new pavement design method, but efforts have been delayed pending the resolution of various technical issues. The procedures and programs are being reviewed by AASHTO member states, and the current plan for adoption is in fiscal year (FY) 2006/07. For Caltrans to be ready to adopt and implement the M-E pavement design method or an alternate pavement design procedure, policy decisions and steps need to be taken beginning this calendar year regarding data collection, presentation, goals, and objectives.

Caltrans' current pavement design practice for flexible pavements uses an empirical design method developed by Francis Hveem derived from road test sections in Stockton and Brighton in the 1940s. The last calibration of the Hveem pavement design method was in 1964 after the AASHTO Road Test (1958-60); the method has not been substantively changed or recalibrated since and has not been kept current with development of new products and materials, which can offer longer-lasting and more cost-effective designs. The Hveem method (which is included in the *Highway Design Manual*, Chapter 600) has performed well through the years but is limited when considering state-of-the-art practices that have been developed. Caltrans' pavement design practices need to be updated in order for California to keep current with advanced pavement design practices, new materials, construction requirements, and integration of

pavement design with pavement management to achieve common pavement performance objectives.

Some of the shortcomings of the Hveem pavement design method include the following:

1. The Hveem method does not account for varying climate conditions in California (for either flexible or rigid pavements).
2. The Hveem method does not account for structural properties of various materials and design features that have been developed since the 1950s (for either flexible or rigid pavements).
3. It is difficult to create pavement design parameters (e.g., gravel factors for flexible pavements, new cross-sections for rigid pavements) for new products using the Hveem method. Caltrans and the Partnered Pavement Research Center (PPRC) must use M-E pavement design procedures to keep current pavement design methods for flexible and rigid pavements up-to-date.
4. The Hveem method is incompatible with pavement design parameters of the 1993 edition of the *AASHTO Guide for Design of Pavement Structures*, leaving Caltrans to conduct its own research and updates rather than using work done by others for AASHTO. All other state DOTs currently are working within the M-E pavement design approach.
5. Using the Hveem method, the accuracy of results for flexible pavement decreases as the Traffic Index (TI) increases. For flexible pavements, extrapolation of the current Hveem data to TIs that are much greater than for which it was last calibrated (in 1964) has been found to result in pavements that are under-designed for fatigue cracking and greatly over-designed for rutting of the subbase and subgrade.
6. The Hveem method was not developed and calibrated for pavement service lives greater than 20 years, resulting in pavements that are much more expensive and difficult to construct than can be designed using the M-E approach (for both flexible and rigid pavements). For example, for flexible pavements, it cannot account for the benefits of polymer-modified asphalts, rich bottom layers, and stiffer asphalts such as those used on the I-710 rehabilitation project in Long Beach. The asphalt thickness on that project was reduced from more than 500 mm, using the Hveem method, to 325 mm using the M-E approach, which resulted in time savings, reduced traffic delays, and reduced construction costs to Caltrans.

7. Using the Hveem method does not provide estimates of pavement condition during the life of the pavement that can be used in life-cycle cost estimation to select the most economical pavement alternative and/or used in the Pavement Management System to estimate future maintenance and rehabilitation needs. The M-E pavement design approach can produce such performance estimates for each distress type.

DISCUSSION:

Adoption of the M-E pavement design method will have the following benefits and impacts:

Benefits

In its fall 2001 newsletter, the NCHRP Project 1-37A team stated the following concerning benefits of M-E pavement design:

The mechanistic-empirical design procedure to be included in the 2002 Guide will allow the designer to evaluate the effect of variations in materials (both inherent and due to construction procedures) on pavement performance. The 2002 Guide will provide a rational relationship between construction and materials specification and the design of the pavement structure. Because the mechanistic procedure will better account for climate, aging, modern materials, and modern vehicle loadings, variation in performance in relation to design life should be reduced. . . . That feature will allow agency managers to make better decisions based on life cycle costs and cash flow.

Based on probabilistic life cycle cost analysis, it is conservatively estimated that improved pavement design procedures will reduce premature failures and result in average annual savings in pavement rehabilitation costs of \$1.14 billion per year over the next 50 years. This analysis was based on a design life of 20 years and the assumption that the percentage of pavement failures within the first 10 years of a pavement's life would drop from 5 percent to 0.5 percent. It was further assumed that the range of performance lives for the remaining pavements, 10 to 30 years for current practice, would increase to 15 to 30 years using the 2002 procedure.

Some of the expected benefits of adopting the M-E pavement design method include the following:

- Create more efficient and cost-effective pavement designs.
- Improve pavement design reliability.
- Reduce pavement life-cycle costs.
- Increase support for cost allocation.
- Predict specific pavement failure modes so they can be minimized.
- Extrapolate from limited field and laboratory pavement data.
- Better evaluate the impact of new pavement load levels and conditions.
- Make better use of available pavement materials.
- Provide tool to do performance reviews of Contractor Incentive Reduction Proposals (CRIPs).
- Better characterize seasonal/drainage effects on pavement.
- Improve pavement rehabilitation design.
- Account for daily, seasonal, and yearly changes in pavement materials due to climate and account for traffic changes.
- Provide the ability to model and calibrate observed pavement performance on state highways to the design of these pavements.
- Provide tools for developing pavement performance models in connection with performance-based specifications.

Based on the few M-E pavement designs done to date, such as the I-710 pavement rehabilitation project in Long Beach, Caltrans has the potential to save from 10 to 40 percent on pavement costs for TI s greater than 12. Additional savings also will be realized in traffic handling costs and construction time.

Impacts

The potential impacts of adopting the M-E pavement design method include the following:

- Modification of what pavement condition data is collected and how it is recorded. Information collected and the pavement design analysis used will need to be compatible. Databases for materials information will need to be developed to reduce the costs of pavement designs using materials used on previous projects.
- More testing and analysis will be needed for designing new complex projects. Because of the increased variables to account for traffic, climate, and materials, designers will need to collect more information, increase the amount of detailed analysis done, and check work more thoroughly. This should be partially mitigated by developing simplified pavement design procedures and/or tables for small projects where savings from a more accurate pavement design are offset by the resources invested to design the pavement.
- Because this is a new pavement design approach, designers will need additional training to become familiar with the new procedures and programs.
- Efforts should begin in correlating the Hveem compactor to the Superpave gyratory compactor in anticipation of the future move to the Superpave mix design system that supports M-E pavement design.

CURRENT EFFORTS:

Caltrans' Division of Design, through its participation on the JTFP, has been involved since 1996 with other states in helping to shape the M-E pavement design methodology developed in NCHRP Projects 1-37 and 1-37A. Through the PPRC – which is managed by the Division of Research and Innovation (DRI) – the University of California, Berkeley, and the University of California, Davis, also aided Caltrans and the NCHRP project teams on technical issues, concepts, needs, and programs. The PPRC currently is evaluating the software developed by the NCHRP Project 1-37A team for accuracy and compatibility to California pavement conditions and performance, and is working with the Division of Traffic Operations to develop improved truck traffic load databases required by the new procedure. The PPRC also has been working on additional modules compatible with NCHRP Project 1-37A to provide improvements that could not be considered within the scope of the NCHRP project due to budget and time constraints. The Division of Engineering Services (DES), through the Office of Pavement Rehabilitation in Materials Engineering and Testing Services (METS), has been

monitoring, checking, and providing input to the Division of Design and the PPRC on NCHRP Project 1-37A.

The Pavement Standards Team has included review of the M-E pavement design method as part of the team's FY2004/05 work plan.

ALTERNATIVES:

Available alternative strategies for Caltrans' pavement design procedures are listed below.

- **Alternative A:** Maintain the existing Hveem pavement design method.
- **Alternative B:** Develop a new performance-based pavement design method to replace the Hveem method.
- **Alternative C:** Evaluate and adopt the M-E pavement design method calibrated for California conditions.

RECOMMENDATIONS:

Alternative C, to evaluate and adopt the M-E pavement design method, is preferred for the following reasons:

1. Caltrans' practices will be more consistent with those of AASHTO and other states, thereby making it easier to share and collaborate on data and improvements.
2. By utilizing the work done by AASHTO, the NCHRP, other state DOTs, and other countries, Caltrans will minimize the effort needed to improve and maintain its pavement design methodology.
3. Project costs will be optimized/reduced and performance improved because pavements will be better designed to meet specific site conditions.
4. M-E pavement design will provide a link with monitoring pavement performance (i.e., pavement management) that will allow Caltrans to calibrate pavement designs on actual pavement performance results.
5. Use of the M-E pavement design method will improve Caltrans' ability to incorporate new pavement materials and construction processes as they become available.

6. The M-E pavement design method offers the ability to design both new pavements and rehabilitation/reconstruction projects using the same approach, as opposed to the current pavement overlay design method that uses an entirely different set of assumptions and inputs.
7. The M-E pavement design method provides analysis and modeling needed for performance-based specification to the designer. This allows incentive/disincentive pay factors for construction quality to be calibrated against effects on pavement performance and cost to Caltrans for future maintenance and rehabilitation, and allows revised estimates of expected pavement performance to be made using the pavement design method based on as-built construction quality. Once the M-E pavement design method is in place, the Division of Construction can use M-E principles to calibrate requirements and incentives/disincentives as part of its separate effort to develop performance-based pavement specifications.

RISKS:

1. During the implementation phase, short-term risks include lack of oversight and poor selection of input values due to inexperience with the pavement design methodology that could result in some premature pavement failures. Providing standards and guidelines on input values and expectations for output values can mitigate this risk.
2. By incorporating a nationwide pavement design process, Caltrans will not have full control of the data inputs and research priorities. This may result in Caltrans having to modify some of its business practices, such as how it records pavement condition data, to be compatible with the national model. However, there is a great deal of flexibility (e.g., different levels of sophistication and cost of the required input data) in the M-E pavement design approach that will permit Caltrans to develop its expertise and level of implementation over time.
3. New testing methods and equipment may be needed to provide the data required for M-E pavement design.
4. Because new methodology is reliant on continuous improvement, failure to provide adequate resources to maintain the procedures and programs will result in the program failing to meet expectations.
5. The project timeline assumes both adoption of the M-E pavement design method by AASHTO to occur in FY2006/07 and the proposed consolidation of the DES-METS' Office of Pavement Rehabilitation and the Division of Design's Office of Statewide Pavement Design to have resultant staffing near the level of both offices today. If either assumption proves to be incorrect, then the project timeline may have to be extended or the project suspended.

EFFECT ON EXISTING LAW:

None. The procedures used to design pavements are currently at the discretion of Caltrans as long as they are based on sound engineering judgment.

ESTIMATED COST:

It is expected that additional resources will be needed to evaluate the proposed M-E pavement design method and to implement the new design procedures. To date Caltrans has invested between \$500,000 and \$1,000,000 in direct and indirect research, and approximately 1.5 PYs in oversight of the PPRC and for participation on the JTFP. It is expected that DES-METS, the DRI, and the Divisions of Design and Maintenance will need to invest 2 PYs per year over the next four to six years to complete the implementation. These resources will be spread as follows:

Design	1.00 PY
District Materials Engineers	0.30 PY
METS	0.25 PY
DRI	0.25 PY
Construction	0.10 PY
Maintenance	0.10 PY

These needs can be covered within existing resources assuming the proposed consolidation of the DES-METS' Office of Pavement Rehabilitation and Design's Office of Statewide Pavement Design is completed at the staffing levels specified in that proposal. Note that some of these resources (particularly for Maintenance) will duplicate efforts currently underway to enhance the Pavement Management System and improve pavement preservation guidance. An additional \$775,000 per year of research funds will be needed over the same time period.

Once completed, the M-E pavement design method will need on average an additional 0.4 PYs (0.2 for Design, 0.1 for the DRI, and 0.1 divided between Construction, METS, and Maintenance) and approximately \$250,000 of research funds per year to maintain the system, although in current dollars this cost will decrease some as additional knowledge is gained and databases of information are developed. An investment of an additional \$500,000 of research funds and 0.5 PYs will be needed approximately every five years to recode software and update/improve pavement design aids to incorporate new knowledge and data, and to account for new pavement materials, structures, rehabilitation strategies,

and construction methods. Some of these costs may be mitigated by collaborating efforts with AASHTO and other states. Note that the resources needed to maintain this new pavement design method are identical to those needed to maintain the existing system and bring it up to current standards. Training will require an additional 3 PYs for both Headquarters and the districts.

ORGANIZATIONAL STRUCTURE:

The Pavement Standards Team will serve as the project development team for this effort: the Division of Design will be the lead and project manager, the DRI will oversee research contracts, and the Pavement Program Steering Committee will provide oversight and ensure that departmental goals and objectives are being met.

TIME FACTOR:

In order to begin reaping immediate benefits of the work done to date on the M-E pavement design method, it is proposed that Caltrans phase in implementation as components are completed. It is expected that it will take four years to fully complete the research and development of criteria, methods, and programs for M-E pavement design. An additional year will be needed to complete implementation. After that, there will be an ongoing need to keep the design methodology and data current in order to ensure the pavement design method provides optimum design and accounts for new pavement products and procedures.

METHOD OF IMPLEMENTATION:

Following are the proposed steps to fully complete adoption of the M-E pavement design method:

1. Complete review and evaluation of NCHRP Project 1-37A programs for M-E pavement design. Submit comments and recommendations for revisions by summer 2005 to AASHTO. Complete research and development on procedures to fill gaps in the NCHRP Project 1-37A procedure.

2. Establish departmental performance measures and criteria for performance-based pavement design. The features that need to be addressed are:
 - a. Pavement climate regions – address differing conditions pavements can face throughout California.
 - b. Roadway classification system for pavements – function- vs. volume-based.
 - c. Distress variables – which distresses will be calculated and tracked.
 - d. Failure parameters – what pavement conditions should exist at construction and end of design life.
 - e. Reliability/variability requirements – how reliable should the results be and what is the acceptable standard deviation.

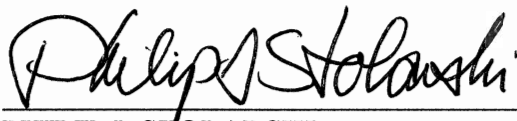
This includes identifying changes to testing and needs for new equipment/resources to implement the M-E pavement design method. Preliminary criteria can be established by summer 2005 and then evaluated and finalized by 2007. The Pavement Standards Team and the districts also will need to develop testing and equipment needs/budgets to develop and maintain M-E pavement design. This should be done during FY2005/06.
3. By summer 2005, develop new rigid pavement design tables (simple design aids) for the *Highway Design Manual* based on the M-E approach and initial pavement performance criteria.
4. Be ready to adopt NCHRP Project 1-37A procedures for rigid and flexible pavement when AASHTO formally adopts the M-E pavement design method. Incorporate California modifications that are either ready to go or necessary to produce results at least as good as current methods. Currently, AASHTO adoption of the M-E pavement design methodology is slated for FY2006/07, but it will be introduced first as an alternative to existing pavement design procedures.
5. Develop a simplified M-E pavement design method for flexible pavement. It is anticipated this will take until 2007 to complete, assuming the PPRC has and is able to commit the resources currently planned for this effort.
6. Introduce a simplified pavement design model for flexible pavement as an option to the current Hveem method. Beta test in FY2006/07. Incorporate into the *Highway Design Manual* in FY2007/08.
7. Phase out the Hveem pavement design method. This would occur over two to three years after the new M-E pavement design method is introduced.
8. Complete California modifications/calibrations to AASHTO M-E pavement design procedures and data. It is estimated this will take until 2008 or 2009 to fully complete, but portions can be implemented as they are finalized.

9. Maintain M-E pavement design procedures and data. Update as required. This is an ongoing effort that will require investment of resources to collect, maintain, and analyze pavement data as well as updating pavement design models and performance standards.

CONCLUSION:

Adoption of the M-E pavement design method currently under development as Caltrans' performance-based pavement design method will be a benefit by reducing pavement costs in projects; improving performance; enhancing Caltrans' ability to incorporate new pavement materials, practices, and procedures; and increasing information sharing with other states, which will reduce Caltrans' costs to maintain and development pavement design methodology.


SUBMITTED BY:

 1/26/05

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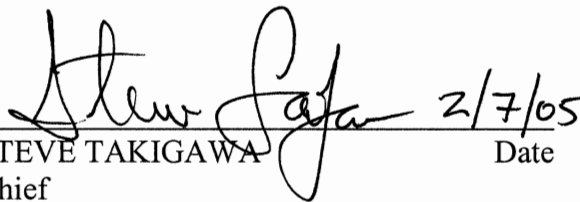
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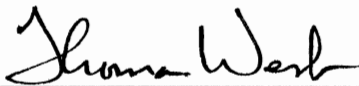
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